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ENERGY LEVELS IN P^{30}

JAMES T. LEWIS
and
CHARLES J. REIDL

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THESIS

ENERGY LEVELS IN P^{30}

by
James T. LEWIS
and
Charles J. REIDL

12ND P2238 (1-59)

ENERGY LEVELS IN P^{30}

* * * * *

James T. Lewis

and

Charles J. Reidl

ENERGY LEVELS IN P^{30}

by

James T. Lewis

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and

Charles J. Reidl

Lieutenant Commander, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
PHYSICS

United States Naval Postgraduate School
Monterey, California

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by

James T. Lewis

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This work is accepted as fulfilling
the thesis requirements for the degree of
MASTER OF SCIENCE
IN
PHYSICS
from the
United States Naval Postgraduate School

ABSTRACT

Energy levels in P^{30} were investigated using a proton beam from the 2 Mev Van de Graaff generator at the U. S. Naval Postgraduate School. Thin targets of high purity natural silicon and silicon enriched to 70.83 percent Si^{29} were bombarded by protons within the energy range 0.85 to 2.00 Mev.

The gamma rays from the 1309-kev $Si^{29}(p,\gamma)P^{30}$ resonance were analyzed by the RCLiac 128 Channel Analyzer, and the following excited states in P^{30} were determined (in Mev):

0.680
2.550
2.720
2.840
2.974
3.868
4.230
6.445
6.490
6.827
6.848
6.995
7.035
7.215
7.255
7.357

The writers wish to express their appreciation for the assistance and encouragement given them by Professor E. A. MILNE in this investigation as well as to K. C. SMITH who provided assistance in the maintenance of electronic equipment, and A. N. GOODALL, OMC, U. S. NAVY who provided assistance in plating the targets.

This project was supported in part by the Office of Naval Research.

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1. Introduction.

This investigation was conducted to determine the energy levels in P^{30} from the $Si^{29}(p,\gamma)P^{30}$ reaction. The proton energy was varied from 0.85 to 2.00 Mev, corresponding to 6.384 to 7.495 Mev excitation in P^{30}.

Naturally-occurring silicon is composed of three isotopes as follows:

Isotope	Percentage (Wt)
Si^{28}	92.21
Si^{29}	4.70
Si^{30}	3.09

When natural silicon is bombarded with protons, three simple capture reactions can occur:

$Si^{28}(p,\gamma)P^{29}$

$Si^{29}(p,\gamma)P^{30}$

$Si^{30}(p,\gamma)P^{31}$

Of the three phosphorus nuclides formed, P^{29} and P^{30} are radioactive, decaying by B^{+} emission with half lives of 4.6 seconds and 2.5 minutes respectively, while P^{31} is stable.

In order to enhance observation of $Si^{29}(p,\gamma)P^{30}$ resonances, silicon enriched in Si^{29} was obtained for bombardment:

Isotope	Percentage (Wt)
Si^{28}	28.46
Si^{29}	70.83
Si^{30}	0.71

Thin targets of natural silicon and enriched silicon were bombarded with protons, and differential excitation

comparison curves were drawn in order to determine and confirm known $Si^{29}(p,\gamma)P^{30}$ resonances. Refer to Figures 4 and 5.

The gamma rays from the 1309 kev $Si^{29}(p,\gamma)P^{30}$ resonance were analyzed by the RCLiac 128 Channel Analyzer, and seven excited states in P^{30} were determined using these gamma energies. Nine additional excited states were determined from the observed $Si^{29}(p,\gamma)P^{30}$ resonances listed in Table II.

2. Resonance and Decay Phenomena

Since 1930 various types of particle accelerators have been developed which have made it possible to study the excited states of light nuclei. When a nucleus is bombarded by a light particle (in this case, a proton), the particle may be merely scattered by the nuclear surface or coulomb field or a compound nucleus may be formed which can decay in a number of different ways. If decay of the compound nucleus is by gamma emission, the excitation function for the (p,γ) reaction can be obtained by measurement of the gamma ray intensity as the incoming particle energy is varied. The observation of resonances indicates that discrete excited states of the compound nucleus are formed, and it is for this reason that the accurate determination of excitation curves is important. An extended analysis of the resonance phenomena has been given by Fowler, Lauritsen and Lauritsen.[1]

Examination of Table I indicates that when silicon is bombarded with protons of less than 2.00 Mev energy (the maximum bombarding energy investigated) gamma ray emission

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[1] W. A. Fowler, et. al., Rev. Mod. Phys., 20, 236 (1948)

and reemission of the proton are the only decay modes energetically possible after proton capture.

In order to form a compound nucleus, the proton must penetrate the coulomb barrier. Classically the coulomb barrier of a Si^{29} nucleus to an entering proton is 4.52 Mev; however, according to quantum theory analysis, there can be formation of a compound nucleus even if the incident proton energy is less than 4.52 Mev and there are particular values of this energy for which the probability of formation of the compound nucleus is relatively large. Many of these large reaction probabilities were observed in the proton energy range of 0.85 to 2.00 Mev, i.e., the nine $Si^{29}(p,\gamma)P^{30}$ resonances listed in Table II.

Gamma rays may arise after inelastic scattering as well as after capture. The lowest energy level of the silicon twenty-nine isotope[2] is 1.28 Mev. A proton of energy greater than 1.32 Mev in the laboratory system of coordinates which strikes a Si^{29} nucleus can be scattered inelastically; but since the probability of this phenomenon is low for the energies employed, it is assumed to add insignificantly to the observed resonances. Since no proton energies greater than 2.00 Mev were used in this investigation, it is therefore assumed that in every event the excited phosphorus nucleus decays by emission of quanta or by reemission of a proton.

[2] P. M. Endt and J. C. Kluyver, Rev. Mod. Phys., 26, 95 (1954)

3. Previous Investigations

The Si(p,γ)P reactions were first studied by Hole, Holtsmark and Tangen[3] in 1941 with proton energies between 300 and 550 kev. Later Tangen[4] conducted more detailed investigations in this same energy range and reported four sharp resonances which he attributed to specific silicon isotopes as follows:

Proton Energy (kev)	Isotope
326	Si^{29}
367	Si^{30}
414	Si^{29}
499	Si^{30}

The next reported investigations were made by Seiler[5] in 1955. His work with natural silicon verified the 414 and 500 kev resonances reported by Tangen and in addition indicated resonances at 622, 675, 698, 703, 732, 760, 778, 944 and 989 kev.

In 1956, Milani, Cooper and Harris at Ohio State University[6,7] investigated the $Si^{29}(p,\gamma)P^{30}$ reaction using silicon enriched to 80.8 percent Si^{29}. They reported resonances at 326, 414, 698, 731, 918 and 957 kev.

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[3] N. Hole, et. al., Z. F. Physik. 118, 48 (1941)

[4] R. Tangen, Kgl. Norske Vid. Selsk. Skr. NR1 (1946)

[5] M. R. Seiler, M. S. Thesis, Ohio State University 1955 & Phys. Rev. 99, 340 (1955)

[6] J. N. Cooper, Annual Report by the Ohio State University Research Foundation, March 16, 1955 - March 15, 1956. RF Project 440, Report No. 6

[7] S. Milani, et. al., Phys. Rev. 99, 645 (1955)

At about the same time, S. P. Tsytko and Iu. P. Antuf'ev[8], reported resonances obtained from natural silicon targets in the proton energy interval from 500 to 2600 kev. They reported new resonances at 619.5, 717, 753, 775, 800, 831, 895, 940, 980, 1520, 1618, 1635, 1647, 1663, 1680, 1699, 1774, 1810, 1849, 1879, 2520, 2543, 2553, 2557.5, 2570 and 2572 kev. They indicated that identification of the reaction corresponding to the resonances were made below 1000 kev. They found no resonances from the $Si^{28}(p,\gamma)P^{29}$ reaction among those identified. Identification was accomplished by the yield of positron activity from thin natural silicon targets.

In 1957, Seagondollar, Woods, De Sousa and Glass[9] bombarded hyper-pure natural silicon, at the University of Kansas, with protons of energies between 300 and 1400 kev. They reported resonances at 326, 369, 414, 501, 622, 697, 776, 836, 943, 957, 979, 1202, 1205, 1291, 1327 and 1394 kev.

During the period 1957-1958, P^{30} energy level determinations were published (all energies in Mev) by C. Van Der Leun[10], P. M. Endt[11], and N. K. Green [12]. See the following page for tabulated values.

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[8] S. P. Tsytko and Iu. P. Antuf'ev, J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 1171 (June, 1956)

[9] L. W. Seagondollar, et. al., Bulletin Am. Phys. Soc. Ser. II, Vol. 2, No. 6, 304 (1957)

[10] C. Van Der Leun, Investigation of Light Nuclei with (p,γ) Reactions, (1958)

[11] P. M. Endt and C. H. Paris, Phys. Rev., 110, 89 (1958)

[12] N. K. Green and R. F. Wiseman, M. S. Thesis, U. S. Naval Postgraduate School, (1958)

P^{30} energy level determinations published during 1957-1958

C. Van der Leun	P. M. Endt		M. V. Green
0.684	0.680	4.296	0.688
0.706	0.708	4.342	1.46
1.45	1.451	4.421	2.00
1.97	1.972	4.501	5.825
2.54	2.538	4.625	5.910
2.72	2.723	4.734	6.183
2.84	2.839	4.929	6.213
2.94	2.937	5.024	6.396
3.02	3.018	5.200	6.435
3.73	3.734	(5.233)	6.775
3.84	3.836	5.412	6.805
3.93	3.926	5.504	6.940
4.14	4.141	5.598	6.975
4.18	4.181	5.700	7.103
4.23	4.230	5.790	7.125
4.30			7.146
			7.204
			7.228
			7.305

4. Equipment

Protons used in this investigation were produced in the 2-Mev Van de Graaff electrostatic accelerator at the U. S. Naval Postgraduate School. This horizontal accelerator was manufactured by High Voltage Engineering Corporation. The proton source is similar to the radio frequency ion source described by C. D. Moak[13]. The accelerated protons were passed through a 25-degree magnetic analyzer to separate ions of unwanted mass. The current through the coils of the magnet was measured by a Leeds and Northrup potentiometer. The energy width of the proton beam was defined by passing the beam through a slit 0.8 millimeters wide at a distance of 2.1 meters from the center of the magnet.

Utilizing plans of Professor E. A. MILNE, the turret target chamber was constructed so that any of four mounted targets could be positioned for bombardment without destroying the vacuum and, at the same time, could be positioned inside a well-type scintillation crystal. In order to accomplish this, four 10-centimeter glass tubes (1.3 cm. O.D.) with targets glyptal-mounted on the outer extremity were fitted to a specially adapted circular brass flange by means of an "O" ring-type seal, spacer and threaded locking nut. This flange was fitted to the beam tube flange utilizing a guide stud and an "O" ring-type high vacuum seal. Target selection was accomplished by rotation of the target flange (See Figure 10).

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[13] C. D. Moak, H. Reese, Jr. and J. M. Good, Nucleonics 9, No. 3, 18 (1951)

An auxiliary vacuum system was installed between the slits and the targets. Valves were arranged so as to make it possible to isolate the target chamber when a change of targets was necessary. The target chamber was partially evacuated before reopening to the auxiliary system. An ionization gauge tube in the auxiliary system measured the vacuum in the target area.

A wire lead-off along the outside of the glass target tube connected the target electrically to a current integrating circuit. A short section of the beam tube next to glass target tube was connected through a ten meg-ohm resistor to the negative terminal of a 300 volt battery. The positive terminal of the battery was grounded. This arrangement prevented the escape of any electrons from the target.

A relay of the integrating circuit was connected to the count switch of a decimal scaler and to a timer. Similarly connected was a solenoid-operated beam shutter which cut the proton beam off and on. This made it possible to commence or stop target bombardment, current integration, timing and counting - all simultaneously. Use of the beam shutter automatically interrupted the beam which prevented overheating and unwanted bombardment of the target without shutting off the Van de Graaff. Also, a simple on-off switch between the shutter coil and the integrator permitted bombardment of the target at any time while the integrator was not running. This simplified focusing of the proton beam. Overheating of the target was prevented during long bombardment periods by

directing a stream of precooled air on the target.

The gamma ray yield from the target was measured by a two-inch diameter, well-type, thallium-activated sodium iodide crystal mounted on a Dumont 6292 photomultiplier tube. The signals were amplified and counted by the scaler previously mentioned (See Figures 9 and 10).

The various energies of the gamma rays from a resonance were measured by a four-inch diameter well-type, thallium-activated sodium iodide crystal mounted on a Dumont 6354 photomultiplier tube. The signals were amplified and analyzed by the 128 channel scaler-analyzer (RCLiac 128 Model 20607). This scaler-analyzer is a pulse height analyzer together with a scaler which is suitable for preset-time and preset-count gross counting. As an analyzer, 127 channels are used for data accumulation and the remaining channel is used as a preset time control. As a scaler, 125 of its channels may be used for count data storage for a preset-time mode of operation. A photograph of the 128 channel analyzer is shown as Figure 11.

5. Target Production

Aluminum, lithium-fluoride and all silicon targets were made by vacuum plating the target material onto discs stamped from five-mil tantalum sheeting. Tantalum "boats" were employed for aluminum and lithium-fluoride evaporations, and tungsten "boats" were employed for all silicon evaporations.

Natural silicon targets were made from hyper-pure silicon

(99.9% pure natural silicon) consisting of the following isotope percentages:

Isotope	Percentage (Wt)
Si^{28}	92.21
Si^{29}	4.70
Si^{30}	3.09

Silicon enriched in Si^{29} targets were made from electromagnetically separated isotopes consisting of:

Isotope	Percentage (Wt)
Si^{28}	28.46
Si^{29}	70.83
Si^{30}	0.71

Silicon enriched in Si^{29} was obtained from Oak Ridge National Laboratories in the form of SiO_2.

Experimentally, it was determined that the minimum thickness of silicon targets was obtained when one-half milligram of SiO_2 was completely evaporated during the plating process with the tantalum discs 15 centimeters away. The pressure during evaporation was maintained at less than 5×10^{-5} millimeters of mercury. Using a rough solid angle and area comparison, it was determined that approximately 0.005 milligrams of SiO_2 was deposited on each target.

6. Experimental Procedure

Prior to investigating silicon, the Van de Graaff was calibrated using lithium fluoride and aluminum targets. The following aluminum resonances[11] and fluorine resonances[14]

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[11] op. cit.

[14] F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys., 27, 153(1955)

were used to determine calibration curve (See Figure 1):

Al^{27} (Ep Mev)		F^{19} (Ep Mev)	
0.771	1.091	0.831	1.290
0.880	1.112	0.8735	1.346
0.918	1.309	0.900	1.372
0.932	1.320	0.9353	
0.991	1.355	1.092	
1.018	1.372	1.137	
1.083	1.379	1.176	

The RCLiac 128 channel analyzer was calibrated (gamma ray energy vs. channel number) for both a four-inch and a two-inch crystal (See Figures 2 and 3). This calibration was accomplished by utilizing previously determined gamma ray decay energies of the following nuclides:

Nuclide	Gamma Ray Energy (Mev)
Na^{24}	1.38
Co^{60}	1.17 and 1.33
Cu^{64}	0.511 and 1.02
Zn^{65}	0.511 and 1.12
I^{131}	0.364 and 0.637
Cs^{137}	0.661
Au^{198}	0.411

Natural silicon and silicon enriched in Si^{29} targets were bombarded with protons of energy 0.85 to 2.00 Mev in magnet current steps of 0.0005 amperes corresponding to energy steps of 0.8 kev. At each magnet current setting, the number of counts, the magnet current and the time of observation (in cycles) were recorded. After each ten readings,

background count was recorded and subtracted from the number of counts (in the correct amount, depending on the time of observation). Rough plots of gamma ray yield vs. proton energy were made to determine resonance peaks. Additional runs confirmed resonance peaks as shown on Figures 4 and 5. These resonance peaks are tabulated in Tables II and III.

A silicon target enriched to 70.83 percent Si^{29} was bombarded with 1309 kev protons. To ensure remaining on the 1309 kev resonance peak and to offset small magnet current fluctuations, the reading on a linear rate meter was maintained at maximum value by small adjustments in magnet current. The gamma rays emitted by excited P^{30} nuclides were detected by the four-inch scintillation crystal, a photomultiplier and preamplifier, and analyzed by the 128 Channel Analyzer. To offset background radiation a run of the same time duration, proton beam energy and environment was made on a blank tantalum target and the results were subtracted in the 128 Channel Analyzer. Gamma ray energies obtained from the 1309 kev resonance are tabulated in Table V.

Observation of the 913, 960, 1309, 1330, 1484, 1524, 1710, 1752 and 1857 kev resonances in the $Si^{29}(p,\gamma)P^{30}$ reaction determined the 6.445, 6.490, 6.827, 6.848, 6.995, 7.035, 7.215, 7.255 and 7.357 Mev excited states in P^{30}.

Neither coincidence measurements nor relative intensity measurements on gamma rays were made in this investigation. These measurements would have greatly aided in making spin and parity assignments to the P^{30} nuclear states, resulting

in a more accurate utilization of the gamma ray energies observed.

It was assumed that the probabilities of gamma transitions among the high energy excited states determined on preceding page (6.445 to 7.357 Mev) were zero. With this assumption in mind, and considering the many investigations made with the consistent observation of the 0.68, 2.550, 2.720, 2.840, and 3.868 Mev gamma rays, it was assumed that these gammas were the transitions from excited states in P^{30} to the ground state. By introducing excited states of 4.230 and 2.974 Mev, all the gamma rays listed in Table V were fitted between the excited states in P^{30} with statistical significance. In this manner the 0.68, 2.550, 2.720, 2.840, 2.974, 3.868, and 4.230 excited states in P^{30} were determined. These determinations are in excellent agreement with the energy levels published by C. Van Der Leun and P. M. Endt (previously mentioned).

7. Resolution of Equipment

Utilizing the ratio of the change in energy to energy, with a slit width of 0.8×10^{-3} meters at a distance of 2.1 meters from the center of the magnet, the energy resolution of the Van de Graaff was computed to be better than 0.2% at one Mev. This corresponds to a two-kev energy width at one Mev. Repeated determinations of resonance peaks during this investigation indicated that the resolution is at least this good.

Specifications for the RCLiac 128 scaler-analyzer state that the integral linearity is better than 1% from Channel 5

to 128 with less than one channel drift per each 20°F rise in temperature. During calibration and repeated experimental runs, integral linearity was observed to be this good and channel drift never exceeded one channel over the entire range of temperature rise.

8. Results

The energy levels in P^{30} obtained as a result of this investigation are contained in Figure 7. Figures 4 and 5 show the experimental resonances obtained from $Si^{29}(p,\gamma)P^{30}$ and $Si^{30}(p,\gamma)P^{31}$ respectively. The primary purpose of this investigation was to determine energy levels in P^{30} from specific resonances; however, many resonances obtained by previous experimenters were confirmed. These resonances are listed in Tables II and III. The increase in background above 1.5 Mev in both natural silicon and silicon enriched in Si^{29} is partly due to a broad $Si^{28}(p,\gamma)P^{29}$ resonance.

In addition, these resonances were utilized as a check of the calibration of the Van de Graaff. It is recommended that thicker targets, i.e., in the order of 0.01 milligrams per target, be used to improve the statistics in determining resonance peaks. All experimenters have reported difficulty in obtaining high yields in order to observe statistically significant resonance peaks. This has been partially traced to target preparation and thickness. The method used by Guseva, Inopin, and Tsytko[15] in preparing targets by directly

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[15] M. I. Guseva, E. V. Inopin, and S. P. Tsytko, J. Exptl. Theoret. Phys. (U.S.S.R.) 36, 1 (1959)

bombarding the target discs of tantalum in a mass spectrograph with the electro-magnetically separated isotope may prove feasible and superior to the "in vacuo" method.

During this investigation, it was found that background subtraction and frequent change of targets were essential to offset, not only stray radiation, but also, the carbon contamination which appeared to increase directly with length of time of target bombardment. Therefore, it is further recommended that at least 24 targets of the element under investigation be prepared for any future investigations.

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TABLE I

Silicon Reactions

Reaction	Q(Mev)	Bibliography
$Si^{28}(p,\gamma)P^{29}$	2.724	2
$Si^{29}(p,\gamma)P^{30}$	5.562	11
$Si^{30}(p,\gamma)P^{31}$	7.292	11
$Si^{28}(p,n)P^{28}$	-14.6	11
$Si^{29}(p,n)P^{29}$	- 5.750	11
$Si^{30}(p,n)P^{30}$	- 5.047	11
$Si^{28}(p,d)Si^{27}$	-14.951	11
$Si^{29}(p,d)Si^{28}$	- 6.246	16
$Si^{30}(p,d)Si^{29}$	- 8.388	16
$Si^{28}(p,\alpha)Al^{25}$	- 7.71	11
$Si^{29}(p,\alpha)Al^{26}$	- 4.816	11
$Si^{30}(p,\alpha)Al^{27}$	- 2.376	11

TABLE II

Resonances in the Capture of Protons by Si^{29}

Energy (kev)	Experimental Half-width (kev)	Relative yield
913	4.0	147
960	3.2	76
1309	5.4	380
1330	8.0	519
1484	14.5	33
1524	5.6	96
1710	8.8	1320
1752	4.8	1100
1857	9.2	800

TABLE III

Resonances in the Capture of Protons by Si^{30}

Energy (kev)	Experimental Half-width (kev)	Relative yield
948	–	107
980	3.2	56
1182	7.2	72
1219	6.4	147
1305	8.0	237
1343	5.6	85
1388	16.0	582
1417	4.0	370
1492	6.4	320
1513	4.8	361
1526	3.2	130
1613	4.8	350
1666	4.4	1380
1777	4.8	2280

Table IV
Magnet Current (amps) vs Proton Energy (mev)

I	E_p	I	E_p	I	E_p	I	E_p
1.1400	.788	1.3200	1.076	1.5000	1.364	1.6800	1.652
1.1450	.796	1.3250	1.084	1.5050	1.372	1.6850	1.660
1.1500	.804	1.330	1.092	1.5100	1.380	1.6900	1.668
1.1550	.812	1.3350	1.100	1.5150	1.388	1.6950	1.676
1.1600	.820	1.3400	1.108	1.5200	1.396	1.7000	1.684
1.1650	.828	1.3450	1.116	1.5250	1.404	1.7050	1.692
1.1700	.836	1.3500	1.124	1.5300	1.412	1.7100	1.700
1.1750	.844	1.3550	1.132	1.5350	1.420	1.7150	1.708
1.1800	.852	1.3600	1.140	1.5400	1.428	1.7200	1.716
1.1850	.860	1.3650	1.148	1.5450	1.436	1.7250	1.724
1.1900	.868	1.3700	1.156	1.5500	1.444	1.7300	1.732
1.1950	.876	1.3750	1.164	1.5550	1.452	1.7350	1.740
1.2000	.884	1.3800	1.172	1.5600	1.460	1.7400	1.748
1.2050	.892	1.3850	1.180	1.5650	1.468	1.7450	1.756
1.2100	.900	1.3900	1.188	1.5700	1.476	1.7500	1.764
1.2150	.908	1.3950	1.196	1.5750	1.484	1.7550	1.772
1.2200	.916	1.4000	1.204	1.5800	1.492	1.7600	1.780
1.2250	.924	1.4050	1.212	1.5850	1.500	1.7650	1.788
1.2300	.932	1.4100	1.220	1.5900	1.508	1.7700	1.796
1.2350	.940	1.4150	1.228	1.5950	1.516	1.7750	1.804
1.2400	.948	1.4200	1.236	1.6000	1.524	1.7800	1.812
1.2450	.956	1.4250	1.244	1.6050	1.532	1.7850	1.820
1.2500	.964	1.4300	1.252	1.6100	1.540	1.7900	1.828
1.2550	.972	1.4350	1.260	1.6150	1.548	1.7950	1.836
1.2600	.980	1.4400	1.268	1.6200	1.556	1.8000	1.844
1.2650	.988	1.4450	1.276	1.6250	1.564	1.8050	1.852
1.2700	.996	1.4500	1.284	1.6300	1.572	1.8100	1.860
1.2750	1.004	1.4550	1.292	1.6350	1.580	1.8150	1.868
1.2800	1.012	1.4600	1.300	1.6400	1.588	1.8200	1.876
1.2850	1.020	1.4650	1.308	1.6450	1.596	1.8250	1.884
1.2900	1.028	1.4700	1.316	1.6500	1.604	1.8300	1.892
1.2950	1.036	1.4750	1.324	1.6550	1.612	1.8350	1.900
1.3000	1.044	1.4800	1.332	1.6600	1.620	1.8400	1.908
1.3050	1.052	1.4850	1.340	1.6650	1.628	1.8450	1.916
1.3100	1.060	1.4900	1.348	1.6700	1.636	1.8500	1.924
1.3150	1.068	1.4950	1.356	1.6750	1.644	1.8550	1.932

12ND 6173

TABLE V

Experimental Gamma Energies (Mev)

$Si^{29}(p,\gamma)P^{30}$ 1309-kev Resonance

0.68	±	.06
1.15	±	.06
1.28	±	.06
1.38	±	.06
1.58	±	.06
1.78	±	.06
2.29	±	.06
2.55	±	.06
2.72	±	.06
2.84	±	.06
3.20	±	.06
3.55	±	.06
3.87	±	.06

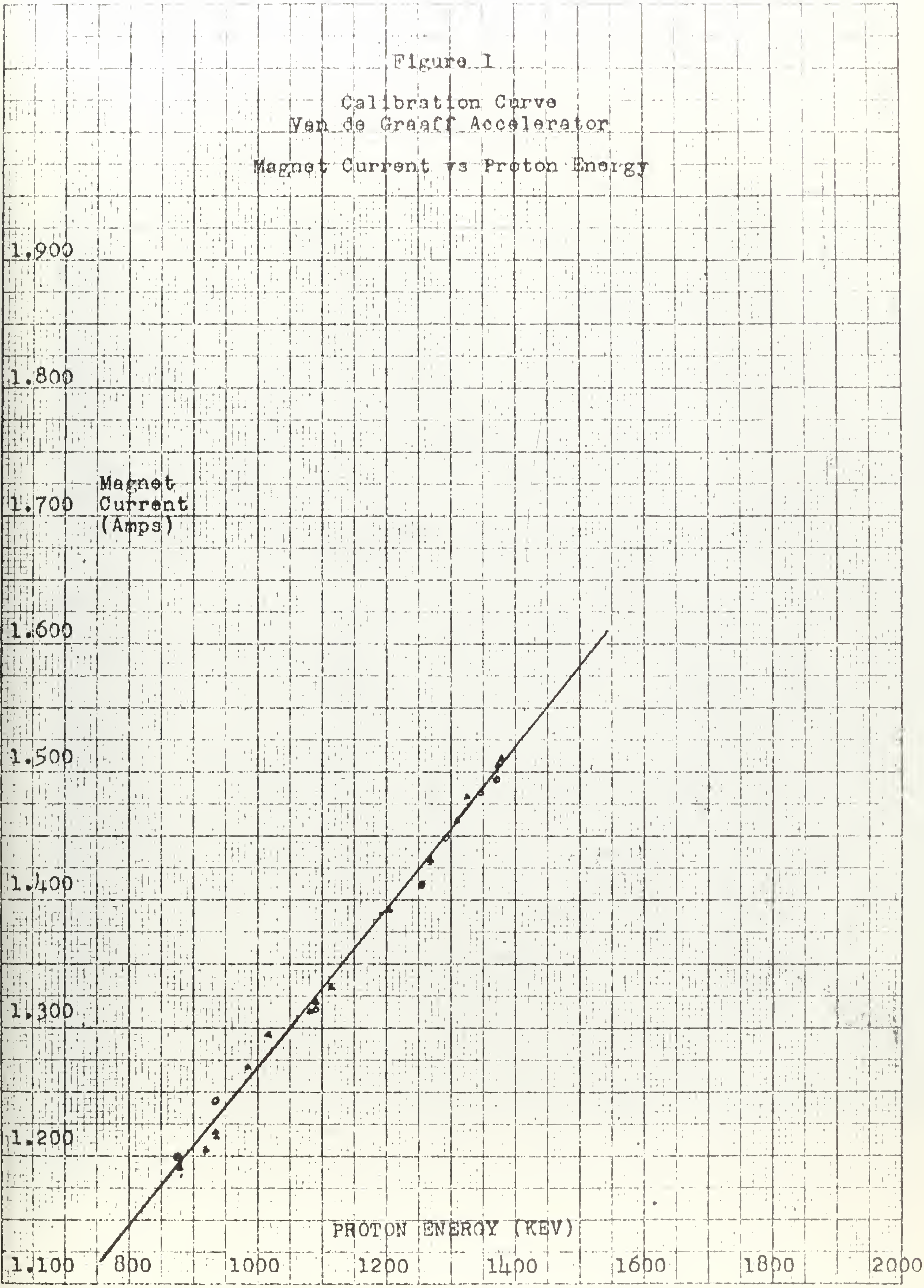


Figure I

Calibration Curve
Van de Graaff Accelerator

Magnet Current vs Proton Energy

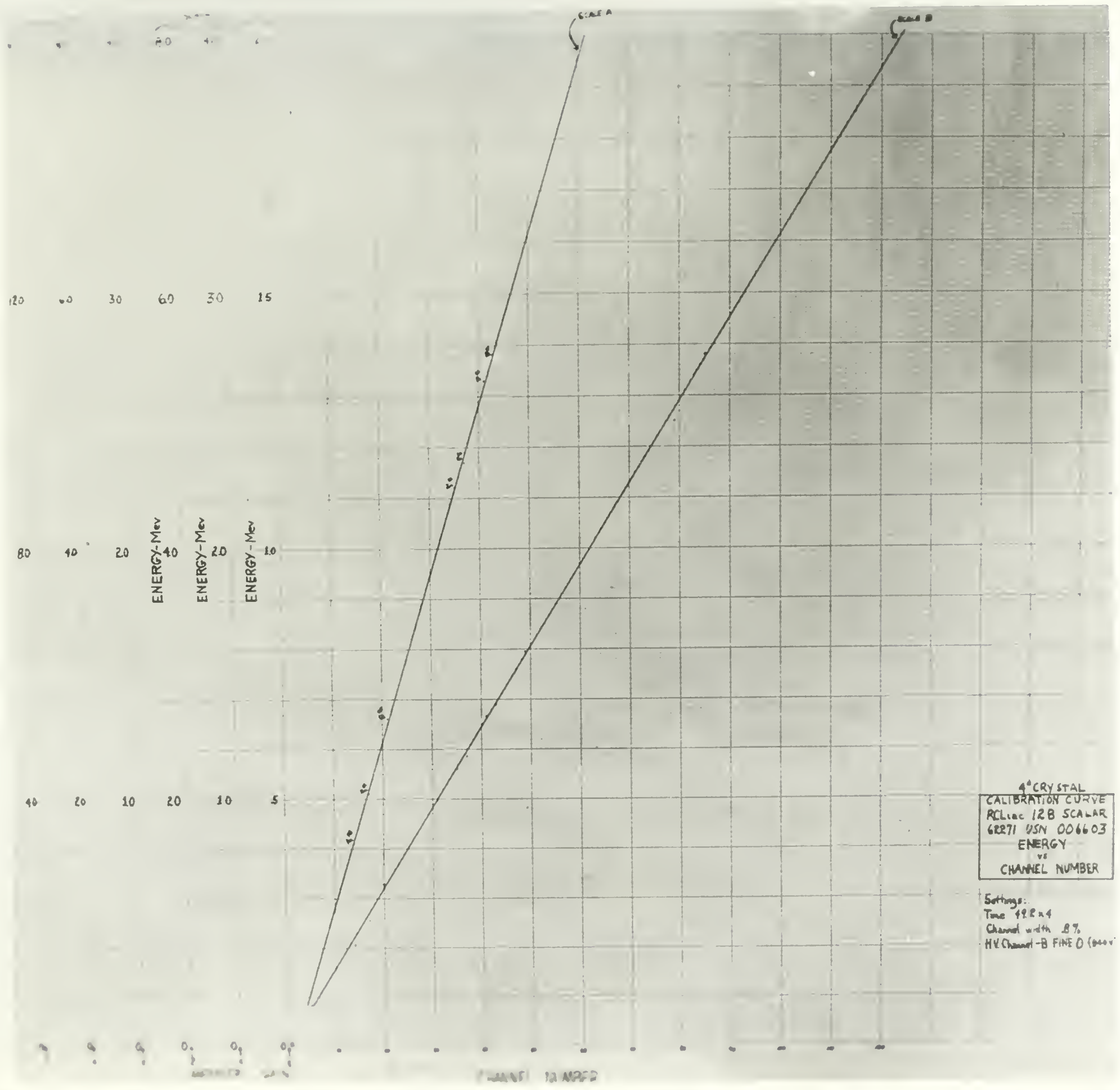

4" CRYSTAL
CALIBRATION CURVE
RCLiac 128 SCALAR
62271 USN 006603
ENERGY
vs
CHANNEL NUMBER
Settings:
Time 19.8 x 4
Channel width .8%
HV Channel -B FINE 0
SCALE A
SCALE B
120
60
30
60
30
15
80
40
20
40
20
10
40
20
10
20
10
5
ENERGY-Mev
ENERGY-Mev
ENERGY-Mev
CHANNEL NUMBER

Figure 2

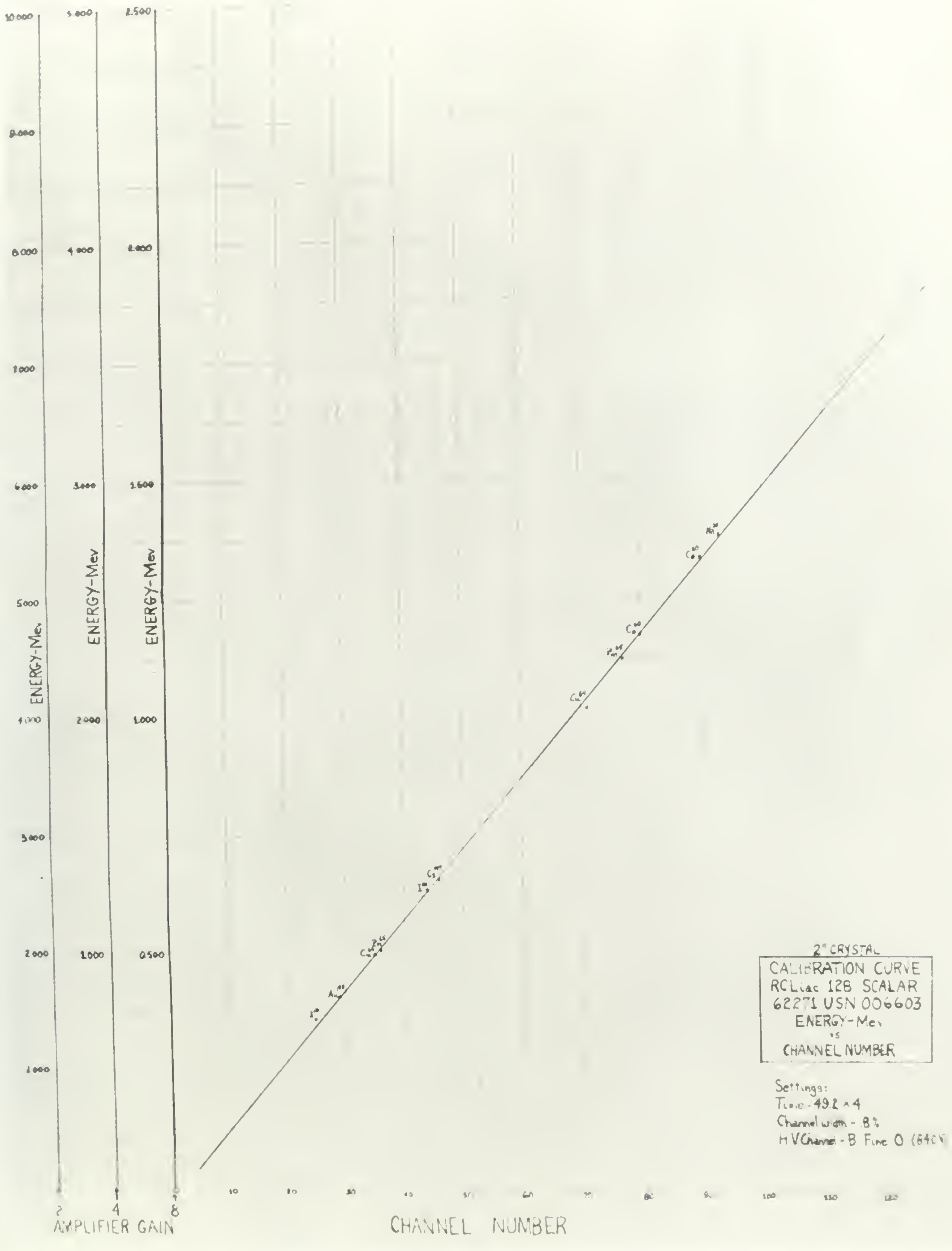

10.000
9.000
8.000
7.000
6.000
5000
4.000
3000
2.000
1.000
ENERGY-Mev
5.000
4.000
3.000
2.000
1.000
ENERGY-Mev
2.500
2.000
1.500
1.000
0.500
ENERGY-Mev
I
Au
Cu
Zn^{65}
I
Cs
Cu^{64}
Zn^{65}
Co^{60}
Co^{60}
Na^{24}
10
20
30
40
50
60
70
80
90
100
110
120
2
4
8
AMPLIFIER GAIN
CHANNEL NUMBER
2" CRYSTAL
CALIBRATION CURVE
RCLiac 128 SCALAR
62271 USN 006603
ENERGY-Mev
vs
CHANNEL NUMBER
Settings:
Time - 49.2 × 4
Channel width - .8%
H V Channel - B Fine O (640V

Figure 3

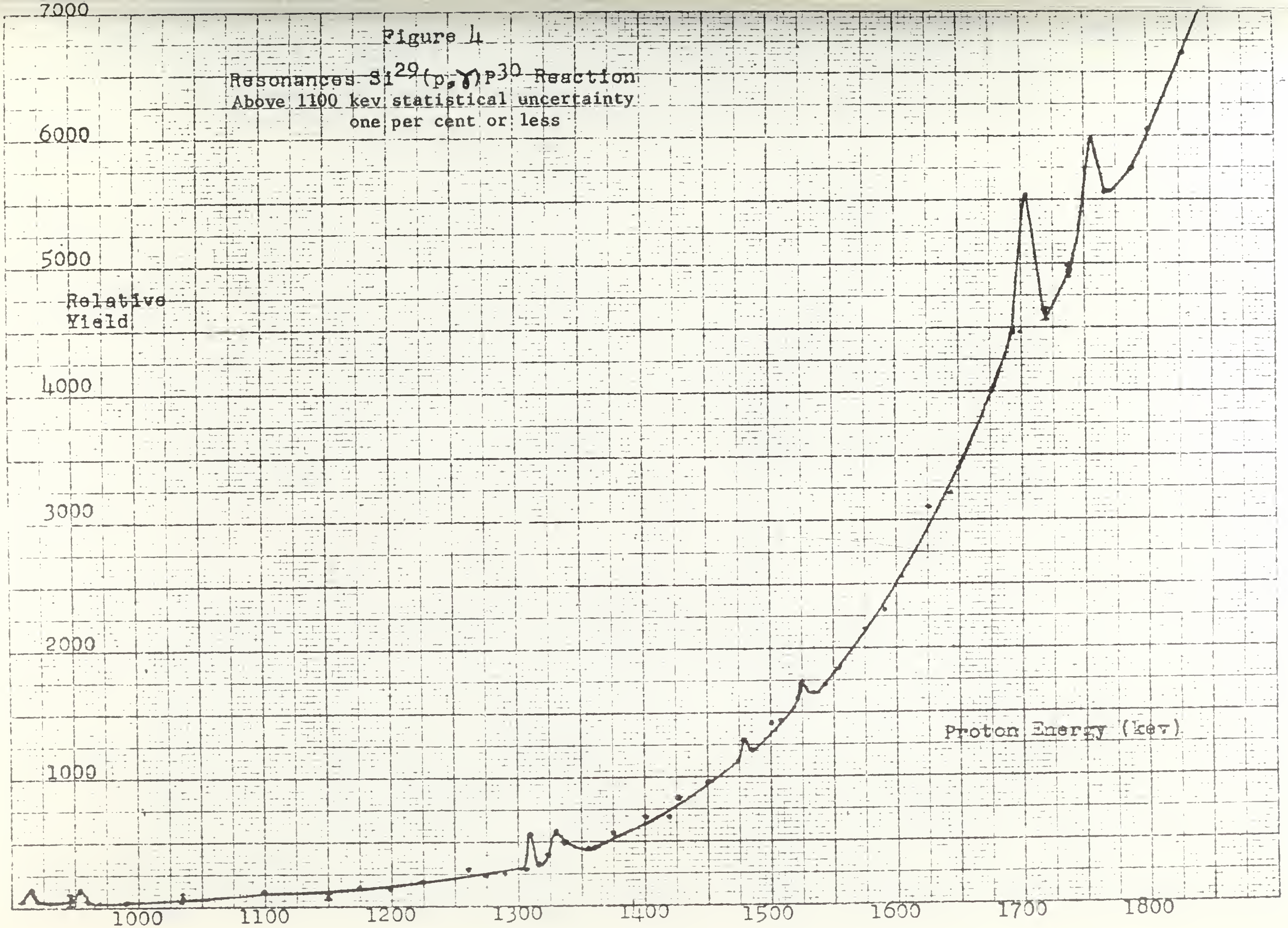


Figure 4

Resonances $Si^{29}(p,\gamma)P^{30}$ Reaction
Above 1100 kev statistical uncertainty
one per cent or less

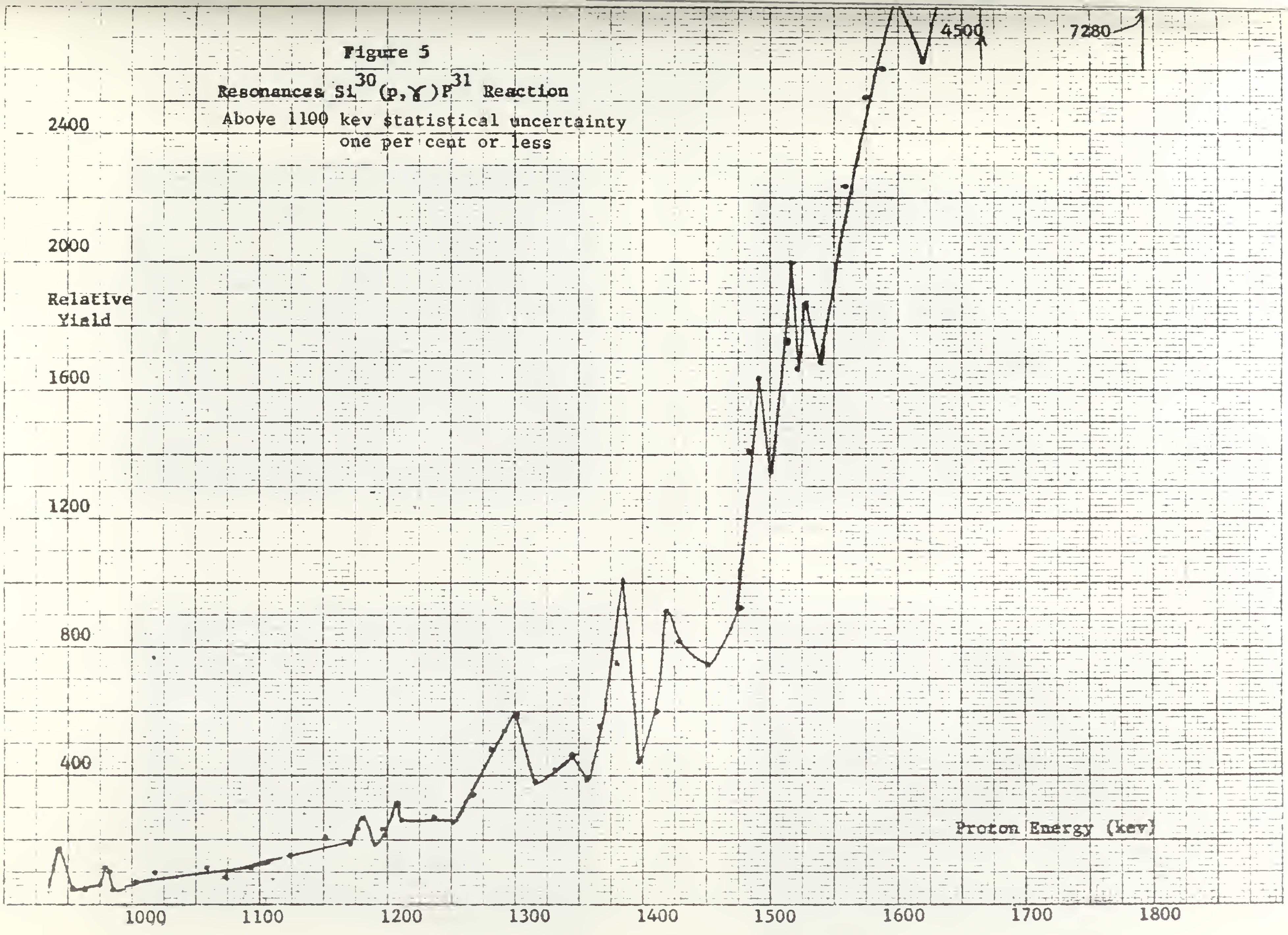
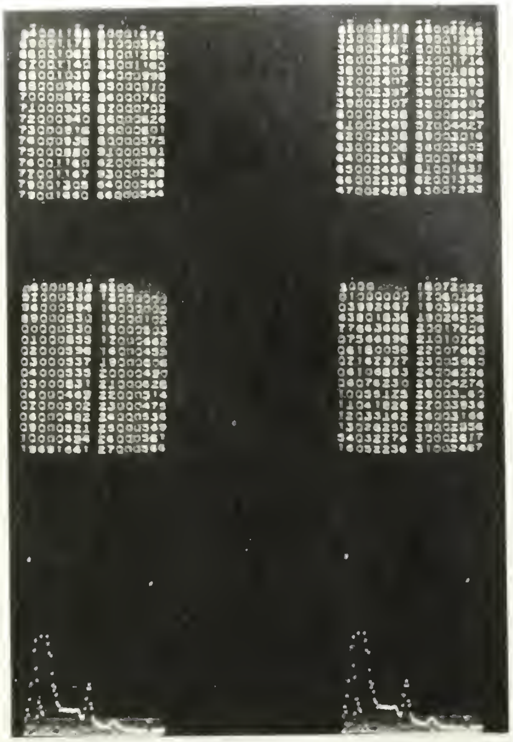


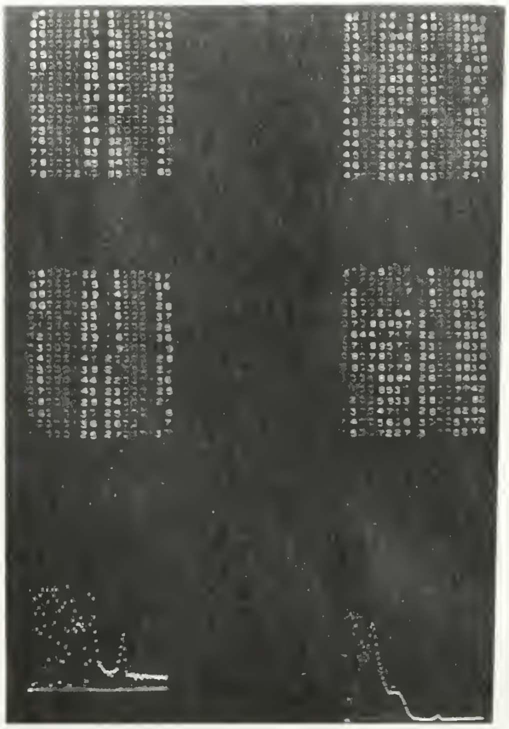
Figure 5

Resonances $Si^{30}(p,\gamma)P^{31}$ Reaction

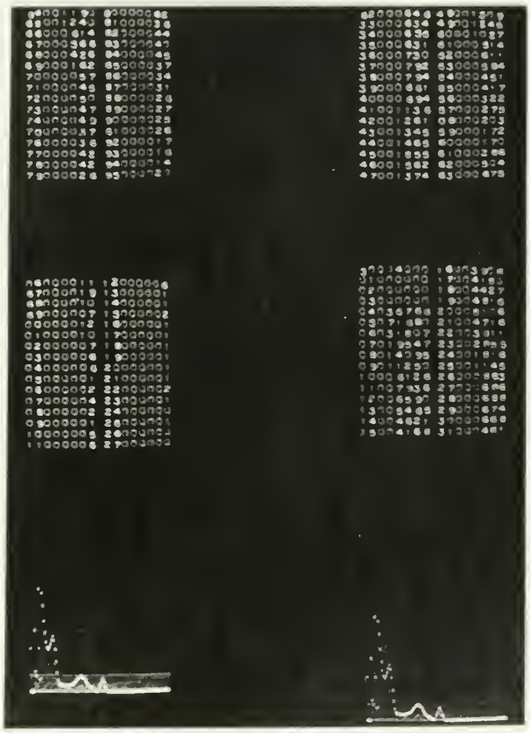
Above 1100 kev statistical uncertainty one per cent or less



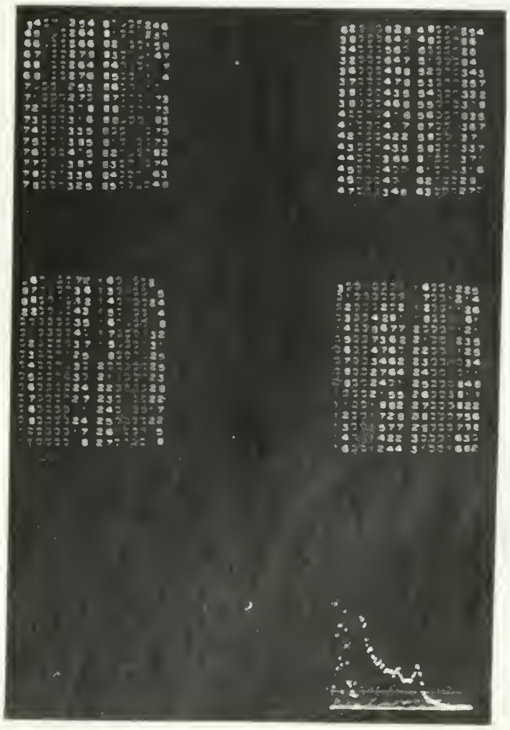
Gain 8 Outside Crystal



Gain 8 Inside Crystal



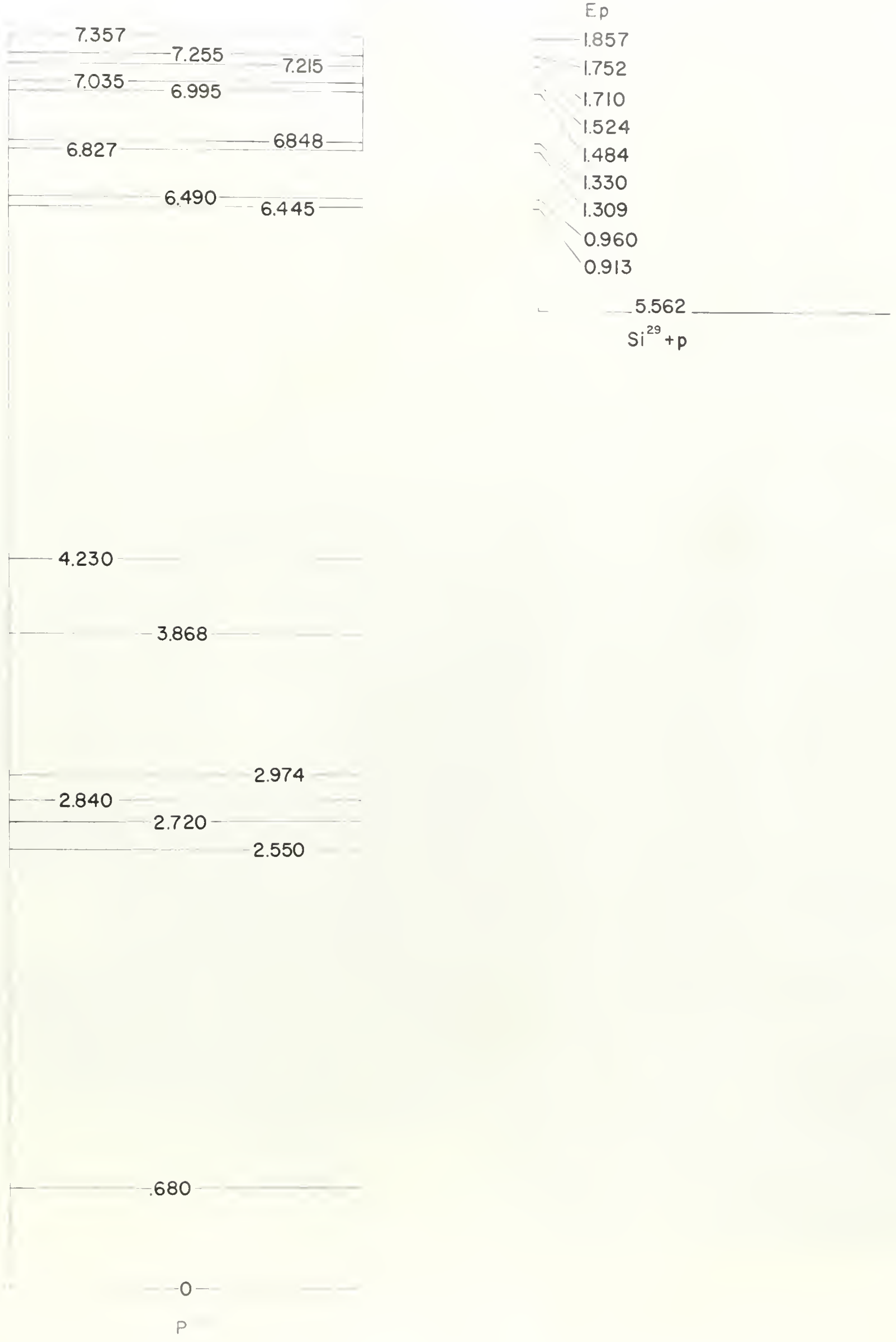
Gain 2 Inside Crystal



Gain 2 Outside Crystal

Figure 6

Figure 7


Ep
1.857
1.752
1.710
1.524
1.484
1.330
1.309
0.960
0.913
5.562
$Si^{29}+p$
7.357
7.255
7.215
7.035
6.995
6.827
6848
6.490
6.445
4.230
3.868
2.974
2.840
2.720
2.550
.680
0
P

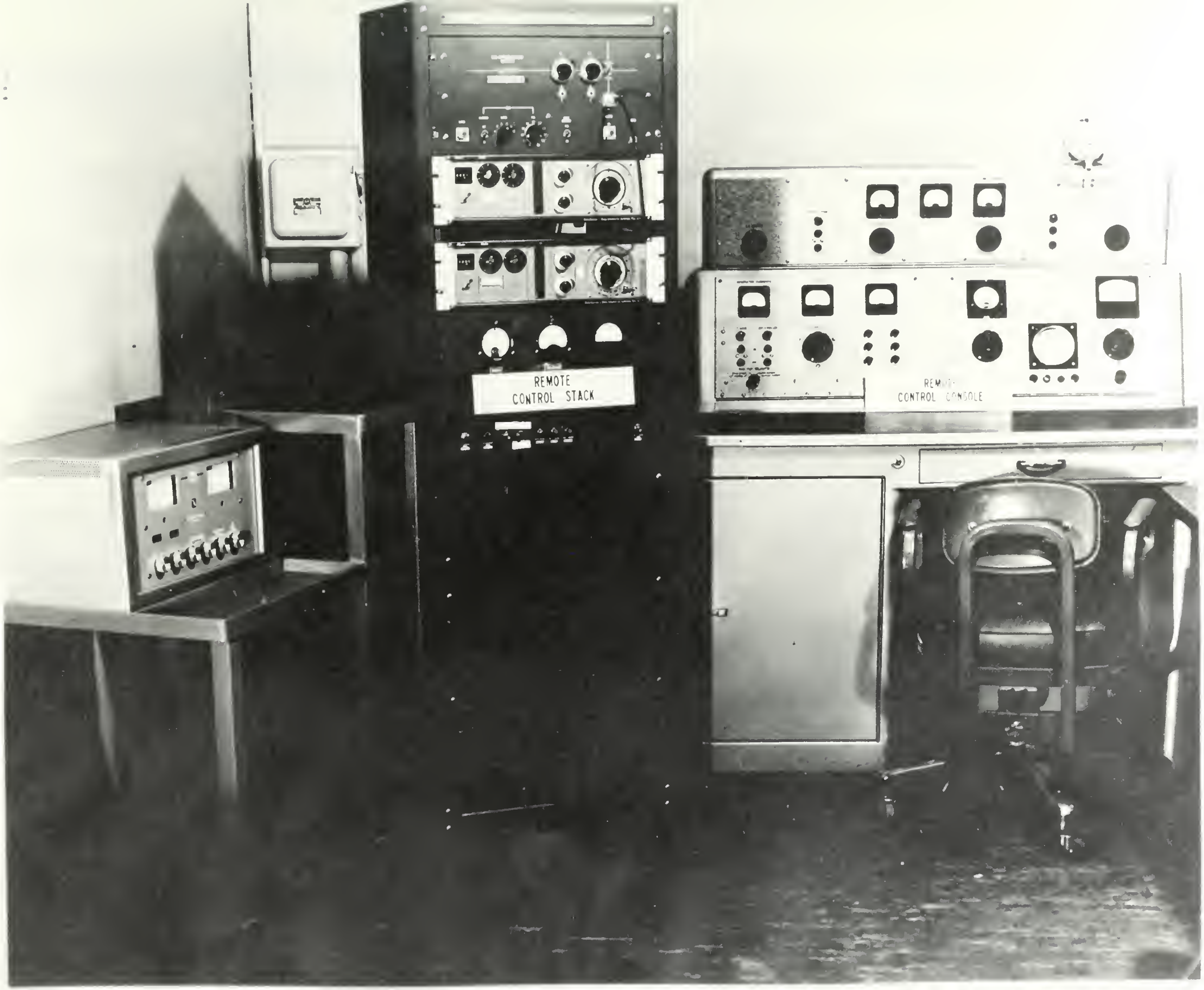


Figure 8

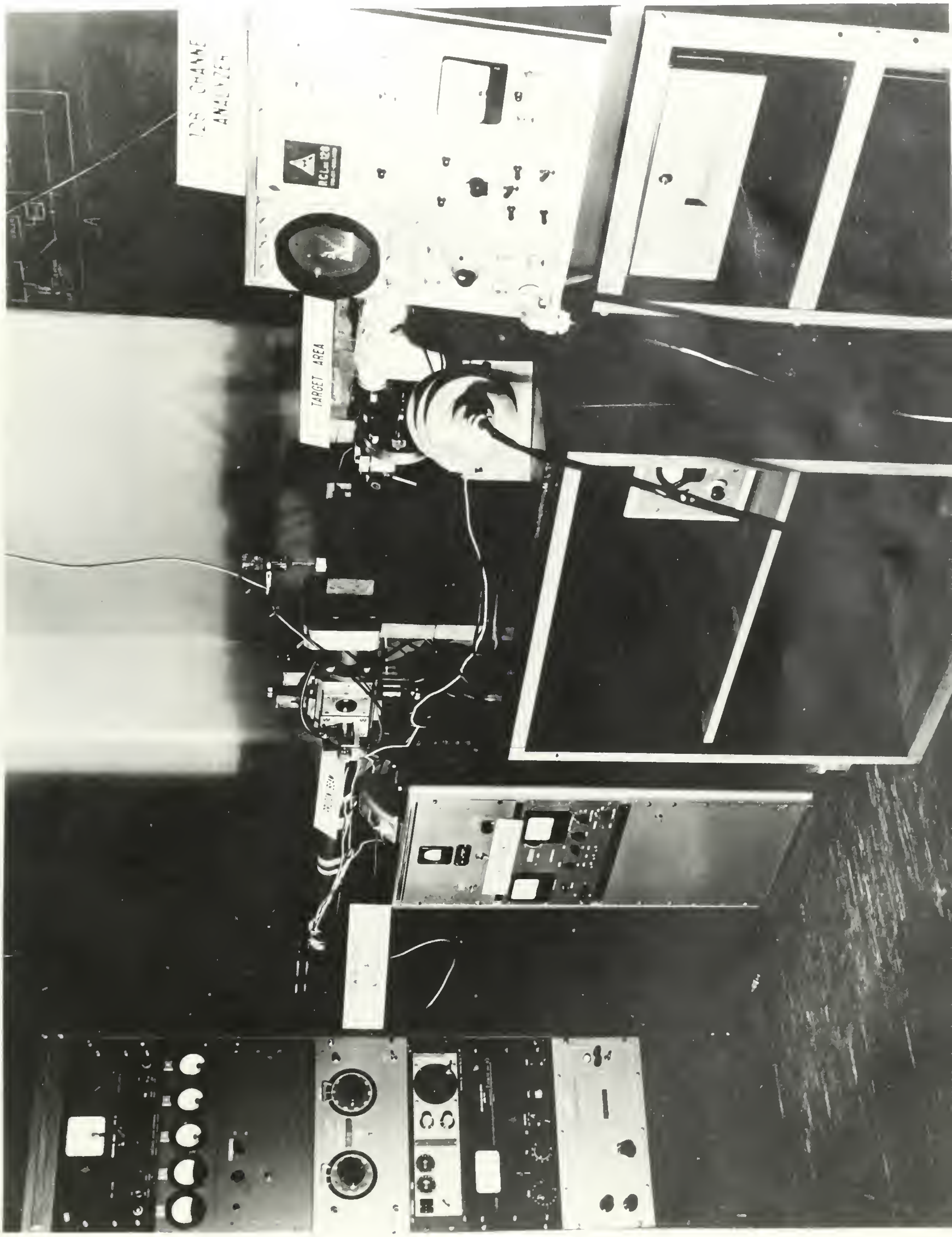


Figure 9

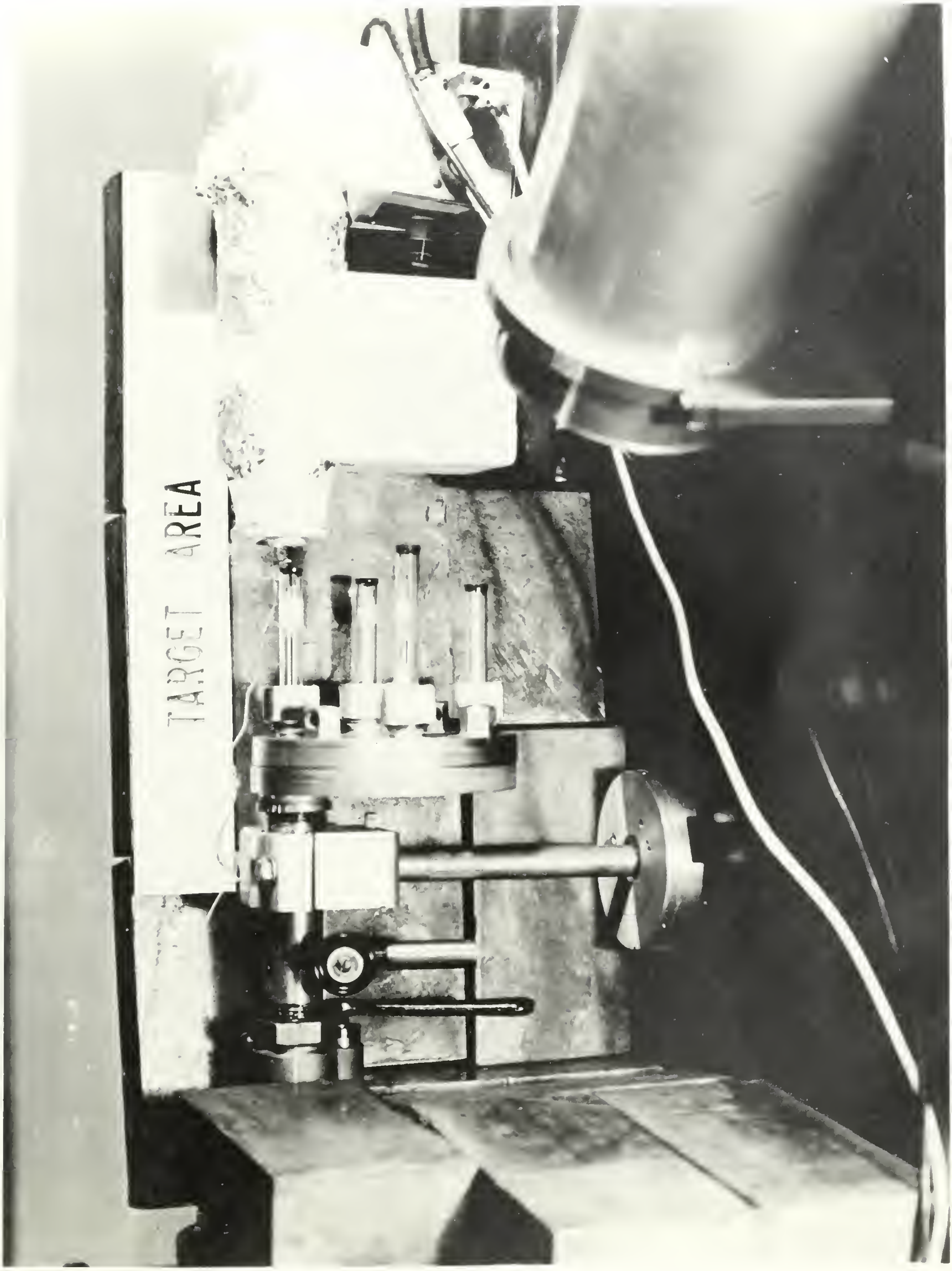
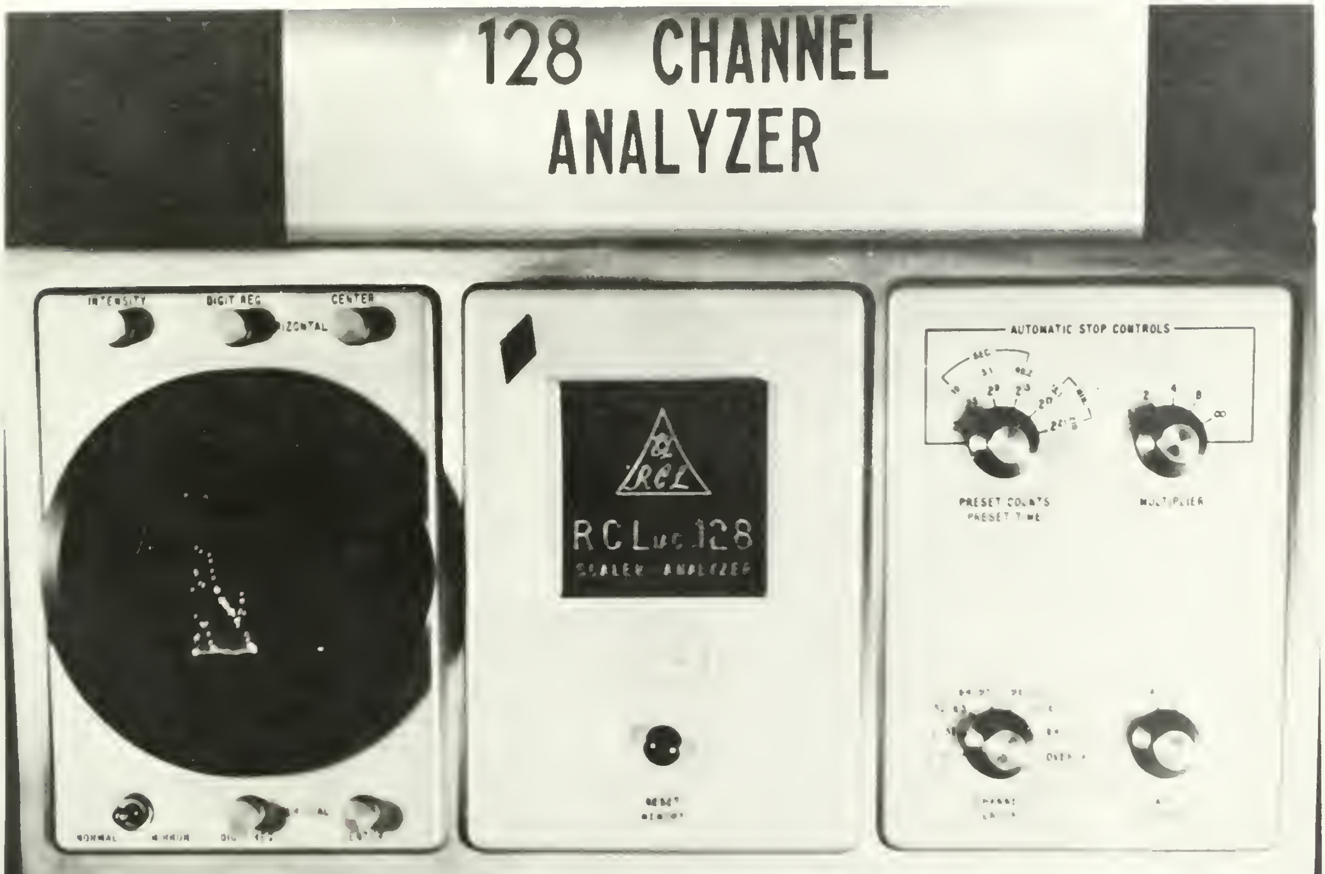


Figure 1C

Figure [illegible]


128 CHANNEL
ANALYZER
INTENSITY
DIGIT REG
CENTER
HORIZONTAL
NORMAL
MIRROR
RCL
RCL uc 128
SCALER ANALYZER
AUTOMATIC STOP CONTROLS
SEC
MIN
PRESET COUNTS
PRESET TIME
MULTIPLIER
2
4
8
∞
RESET
MEMORY
DISCRIMINATOR
LOWER LEVEL
UPPER LEVEL
ZERO LEVEL
CHANNEL WIDTH
5%
2%
PULSER AMPLITUDE
PULSER
AMPLIFIER GAIN
OFF
RESET ADDRESS
PRESET TIME
PRESET COUNT

thesL61
Energy levels in p(30) /
3 2768 002 11884 6
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